

ALUMINUM-COPPER-NICKEL ALLOY AS A
POSSIBLE SUBSTITUTE FOR ALPHA BRASS
FOR USE IN CARTRIDGE CASES

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COLLEGE OF ENGINEERING

THESIS

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SUBJECT "Aluminum-Copper-Nickel Alloy as a Possible Substitute
for Alpha Brass for Use in Cartridge Cases."

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DEPARTMENT OF Metallurgy CLASS OF 1931

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-Thesis

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Aluminum-Copper-Nickel Alloy as a Possible
Substitute for Alpha Brass for Use in Cartridge Cases.

I Introduction.

1. The present tendency toward reduction of armaments in general and reduction in size of men-of-war in particular keeps the Navy Department constantly on the lookout for improvements which will cause an increase in battle-worthiness of the vessels it is allowed. In former times the general policy was to first decide on armor, armament, and speed of the vessel and then design a hull capable of carrying the load. At the present time, with tonnages limited by treaty, the problem is exactly reversed. The size of the hull is fixed and then armor, armament, and speed balanced to fit. Consequently, any reduction in dead weight is highly desirable, and the outstanding opportunity for effecting this reduction is to substitute light metal alloys for the heavier metals and alloys in as many places as possible.

2 Certain types of Naval vessels employ fixed ammunition¹ exclusively while others employ it in certain groups of their guns. Those using fixed ammunition exclusively are the smaller vessels where a saving in weight of dead load means a material increase in battle-worthiness. As a further consideration, however, the reduction in weight of the unit charge is important when it is realized that with even the most modern mechanized loading apparatus the charge is manually handled at one or more points in the

1. The present tendency toward reduction of weight in general and reduction in size of warships is particularly acute for the Navy Department consistently in the last few years. The Navy Department has been in constant touch with the War Department in regard to the reduction of the weight of the ship's structure. In former times the general policy was to first decide on the amount of weight to be saved and then design a hull capable of carrying the load. At the present time, with economy limited by cost, the question is usually reversed. The size of the hull is fixed and then error is made in the amount of weight to be saved. Consequently, the reduction in dead weight is highly desirable, and the opportunity for effecting this reduction is to substitute light metal alloys for the heavier metals and alloys in as many places as possible.

2. Details of the Navy's efforts to reduce weight in general, especially in the case of the battleships, are given in the following pages. It is certain that the Navy Department has been in constant touch with the War Department in regard to the reduction of the weight of the ship's structure. In former times the general policy was to first decide on the amount of weight to be saved and then design a hull capable of carrying the load. At the present time, with economy limited by cost, the question is usually reversed. The size of the hull is fixed and then error is made in the amount of weight to be saved. Consequently, the reduction in dead weight is highly desirable, and the opportunity for effecting this reduction is to substitute light metal alloys for the heavier metals and alloys in as many places as possible.

ammunition supply chain.

The present work was undertaken with the hope of determining a light alloy which might be suitable for use in cartridge cases. A rough estimate places the possible reduction in weight of the unit charge at 15-30 percent.

3. In adapting a light alloy to such use many difficulties are encountered. The alloy must have the following properties: (1) low specific gravity; (2) melting point and thermal conductivity sufficiently high to enable it to withstand elevated temperatures for short intervals of time; (3) strength and hardness to enable it to withstand accidental knocks in handling and prevent its extrusion into the extractor recess during firing; (4) sufficient elasticity to cause it to spring at the instant of firing and allow the gun to take the load, subsequently returning to its initial form when the pressure is released; (5) ductility to allow deep drawing during manufacture. Physical properties of an alloy as usually determined will give only a good indication of how that alloy will act in a particular application. The present instance is not an exception to this statement and it is admittedly true that in this case they will give only a general indication. The only worthwhile test must be the actual use of the alloy for the particular purpose.

Light alloys have been tried for this purpose with no apparent success as yet.² That work is being continued with the assistance of the Aluminum Company of America's Engineer Sales Department but it is confined to adaptations of the standard commercial alloys.

The amount of alloying elements is determined by the type of alloying element which is to be added. The amount of alloying element is determined by the type of alloying element which is to be added. The amount of alloying element is determined by the type of alloying element which is to be added.

4. In addition to the alloying element, the amount of alloying element is determined by the type of alloying element which is to be added. The amount of alloying element is determined by the type of alloying element which is to be added. The amount of alloying element is determined by the type of alloying element which is to be added.

Aluminum alloys have been used for the purpose of... The amount of alloying element is determined by the type of alloying element which is to be added. The amount of alloying element is determined by the type of alloying element which is to be added.

4. From an inspection of the literature 3,4,5,6,7 the conclusion was reached that a suitable light alloy might be found in the Aluminum-Copper-Nickel system. It was previously known that alloys 2S⁹ and 51S¹⁰ had been tried. The alloy 2S (commercially pure aluminum) gave fair results but was far from a success due to its softness. The alloy 51S as used was practically a total failure. From this it might be considered that the melting point of the 2S was sufficiently high, and the melting point of the 51S was sufficiently low, due to alloying additions, to prevent or allow intergranular melting. A permissible assumption is that a light Aluminum-Copper-Nickel alloy with a melting point near that of the 2S and strength and hardness superior to that of the aluminum might be successful.

5. The alloys to be investigated were basically the 96Al-4Cu alloy with $\frac{1}{2}$, 1, 2, and 4% nickel substituted for an equivalent amount of aluminum. The general plan of work consisted of

- (1) Determining liquidus and solidus for each alloy.
- (2) Determining effect of nickel content by
 - (a) Microstructure study
 - (b) Hardness tests
- (3) Determining physical properties with various heat treatments.

6. It is desired at this point to make the following acknowledgements:

- (1) To Commander W.E. Brown, U.S. Navy, for his initial suggestion and subsequent help.

conclusion was reached that a suitable light alloy might be found in the aluminum-copper-nickel system. It was previously known that alloys of Al and Cu¹ had been tried.

The alloy 28 (compositionally pure aluminum) gave the best results for use in the form of a rod due to its softness. The alloy 29 as used was practically a total failure. From this it

might be concluded that the melting point of the 28 was sufficiently high, and the melting point of the 29 was sufficiently low, due to alloying conditions, to prevent or slow intergranular melting. A tentative assumption is that light aluminum-copper-nickel alloy with a melting point near that of the 28 and strength and hardness superior to that of the aluminum might be successful.

5. The alloys to be investigated were basically the 28Al-4Cu alloy with 1, 2, 3, and 4% nickel substituted for an equivalent amount of aluminum. The general idea of work consisted of

- (1) Determining liquidus and solidus for each alloy.
- (2) Determining effect of nickel content of
 - (a) microstructure
 - (b) hardness tests
- (3) Determining physical properties with various heat treatments.

6. It is hoped at this point to make the following

- conclusions:
- (1) To determine the effect of nickel on the
- liquidus temperature and hardness.

(2) To Mr. E. H. Dix, Jr. of the Aluminum Company of America and his staff for furnishing the alloys and subsequent assistance and advice in the metallographic work and in making the tensile specimens.

(3) To Mr. G. F. Halliwell of the Carnegie Institute of Technology faculty for his advice and assistance.

II. Material, Apparatus, and Methods

1. The analyses of the four alloys used are shown in Plate 1. They were prepared and analyzed at the Research Laboratory, Aluminum Company of America, New Kensington, Pa. The base metal was the high purity grade of aluminum known as grade 7A.¹¹

2. A small nichrome-wound resistance furnace was used for the study of effects of heat treatment. Temperature control was entirely by hand. The temperatures were determined by a noble-metal thermocouple which was calibrated against a secondary standard of known accuracy. The potentiometers used were (1) a Leeds and Northrup Type K for the solidus and liquidus determinations and (2) a Leeds and Northrup portable type, calibrated against the Type K, for temperature control of the furnace. A "drop-bottom" for the furnace was built which would permit a quenching interval of approximately $1/5$ second. The temperature differences within the furnace at 600°C . at the level of the platform were 4°C . from side to center, 4°C . to a distance of $1\frac{1}{2}$ " above the platform.

(1) To Mr. W. D. King, Jr., of the Aluminum Company of America and his staff for furnishing the alloys and subsequent assistance and advice in the preliminary work and in making the specific specimens.

(2) To Mr. G. V. Bellwell of the Carnegie Institute of Technology for his advice and assistance.

III. General Apparatus and Methods

I. The subject of the four alloys used are shown in Table I. They were prepared and analyzed at the Research Laboratory, Aluminum Company of America, New Kensington, Pa. The base metal was the high purity grade of aluminum known as Grade 1A.¹¹

A small aluminum-oxide resistance furnace was used for the study of effects of heat treatment. Temperature control was entirely by hand. The temperature was indicated by a radio-thermal thermopile which was calibrated against a secondary standard of known accuracy. The alloys used were (1) a lead and hydrogen Type E for the initial and liquidus determinations and (2) a lead and hydrogen potable type, annealed metal, the Type E for temperature control of the furnace. A "drop-bottom" test furnace was built which would permit a weighing furnace at approximately 1/2 second. The temperature difference within the furnace at 100°C. at the level of the platform was 5°C. from side to center & 0.1°C. at a distance of 1-2" above the platform.

9. Procedure

(1) Using carbon crucibles and with the thermocouples immersed in the metal and protected from it by a silica tube. cooling and heating curves were taken on each of the four alloys to determine their solidus and liquidus temperatures. At least two curves were taken on heating or cooling each alloy and in most cases three or more. The results, as tabulated in Plate 2, are believed to be accurate within 5°C .

(2) After determining the solidus and liquidus temperatures samples $\frac{1}{2} \times \frac{1}{2} \times \frac{1}{8}$ " of each alloy were cut. Taking them in groups of four (one of each alloy) they were placed in the furnace, which had been rigged with the drop-bottom, and given the following heat treatment: heated to a temperature of 590°C . and maintained at that temperature ($\pm 50^{\circ}\text{C}$.) for $\frac{1}{2}$ hour. The furnace was then allowed to cool slowly to various temperatures ranging from 247°C . to 540°C . and after holding at this temperature $\frac{1}{2}$ hour the specimens were quenched. The necessity of this fast quenching is obvious. The resulting specimens were then polished and etched with 1% HF (swab, 8 sec.). They were studied to determine the amounts and nature of the inclusions. Four typical examples of the structures are shown in the accompanying micrographs (Plates 3-6).

(3) One group of specimens was then maintained at 618°C . for $\frac{1}{2}$ hour and quenched. Upon polishing and etching with the 1% HF it was seen that incipient melting had commenced. This is shown in Plate 7 for alloy #2. Similar conditions were noted in the other three.

(4) Hardnesses (Rockwell B) were taken immediately upon quenching in an effort to determine the advent of any precipi-

At various stages during the investigation, the specimens were polished and etched with the following solutions in the metal and protected from it by a silica layer. The cooling and heating curves were taken on each of the four alloys to determine their solidus and liquidus temperatures. At least two curves were taken on heating or cooling each alloy and in most cases three or more. The results are tabulated in Table 3. It is believed to be accurate within $\pm 0.5^\circ\text{C}$.

(3) After determining the solidus and liquidus temperatures of the alloys, samples of $\frac{1}{2}$ inch diameter of each alloy were cut. Taking them in groups of four (one of each alloy) they were placed in the furnace which had been fitted with the drop-bottom and given the following heat treatment: heated to a temperature of 350°C . and maintained at that temperature for $\frac{1}{2}$ hour. The furnace was then allowed to cool slowly to various temperatures ranging from 247°C . to 240°C . and after holding at this temperature $\frac{1}{2}$ hour the specimens were quenched. The necessity of this last quenching is obvious. The resulting specimens were then polished and etched with 10% (weight) HNO_3 . They were etched to determine the amount and nature of the inclusions. Four typical examples of the inclusions are shown in the accompanying micrographs (Plates 3-6).

(4) One group of specimens was then maintained at 418°C . for $\frac{1}{2}$ hour and quenched. Upon polishing and etching with the 10% it was seen that inclusions were present and numerous. This is shown in Plate 7 for alloy No. 1. Similar specimens were noted in the other three.

(5) Specimens (Nos. 1-3) were taken immediately upon quenching in an effort to determine the amount of any precipi-

tation. The results are plotted in Plate 8.

(5) A group of specimens were quenched after soaking for $\frac{1}{2}$ hour at 590°C . and then aged at various temperatures ranging from 100°C . to 450°C . for an additional $\frac{1}{2}$ hour. The aging at 100°C . was done in boiling water and at the higher temperatures in the nichrome-wound furnace. They were air cooled from the aging temperatures. Hardness (Rockwell E, $1/8$ " ball, 100 kg. load, B scale) was taken after aging and the results plotted as shown in Plate 9.

(6) The #1 and #4 half-inch plates were then rolled down, first hot and then finished with a 50% cold reduction. the final thickness was 0.064" (14 gage, A.W.G.). Flat tensile coupons were then punched and milled. A series of the test pieces were heat-treated as in (5) and physical properties determined for the two alloys in the cold-rolled and heat-treated conditions. At least two specimens were tested for each alloy and heat-treatment. The average results are plotted in plates 10-12 inclusive.

(7) The microstructure of alloys #1 and #4 after quenching and aging at 100°C . is shown in plates 13 and 14.

III Data and Results

10. Index of Plates

Plate 1. Chemical Analysis of Alloys

2. Solidus and Liquidus Temperatures
3. Microstructure Alloy #1, as quenched from 590°C.
4. " " #2 " " " "
5. " " #3 " " " "
6. " " #4 " " " "
7. " " #2 " " " 618°C.
8. Hardness vs. Quenching Temperatures, all alloys, hot-rolled
9. Hardness vs. Aging Temperatures, all alloys hot-rolled
10. Physical Properties vs. Heat Treatment, #1 alloy
11. " " vs. " " #4 "
12. Tensile Strength and Elongation vs. Heat Treatment, #1 and #4 alloys
13. Microstructure #1 alloy cold-rolled, quenched and aged at 100°C.
14. Microstructure #4 alloy, cold-rolled, quenched and aged at 100°C.

PLATE 1

Alloy	Si	Fe	Cu	Ni	Al (diff.)
#1	.04	.01	4.20	.56	95.19
#2	.02	.01	4.16	1.10	94.71
#3	.03	.02	4.00	2.00	93.95
#4	.03	.03	4.04	4.05	91.85

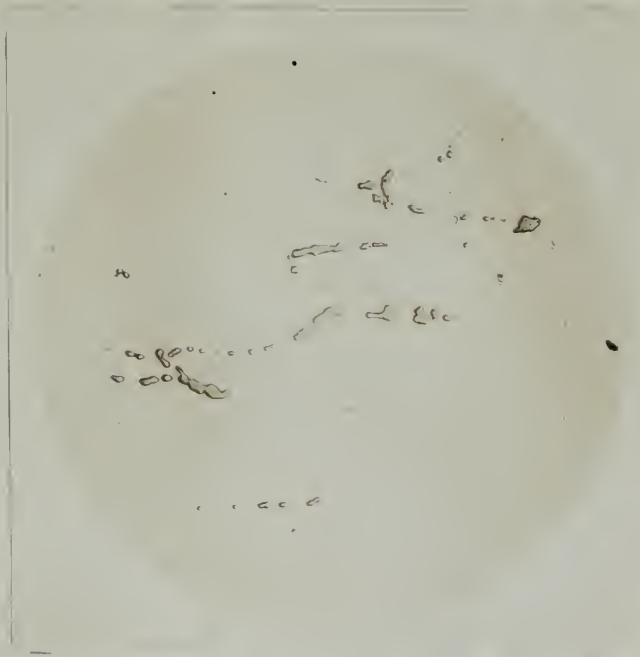
ANALYSES OF ALLOYS

PLATE 2

Alloy		#1	#2	#3	#4
Liquidus	Heating	648	646	637	635
	Cooling	645	641	640	636
Solidus	Heating	620	620	625	618
	Cooling	617	620	620	617

Degrees Centigrade

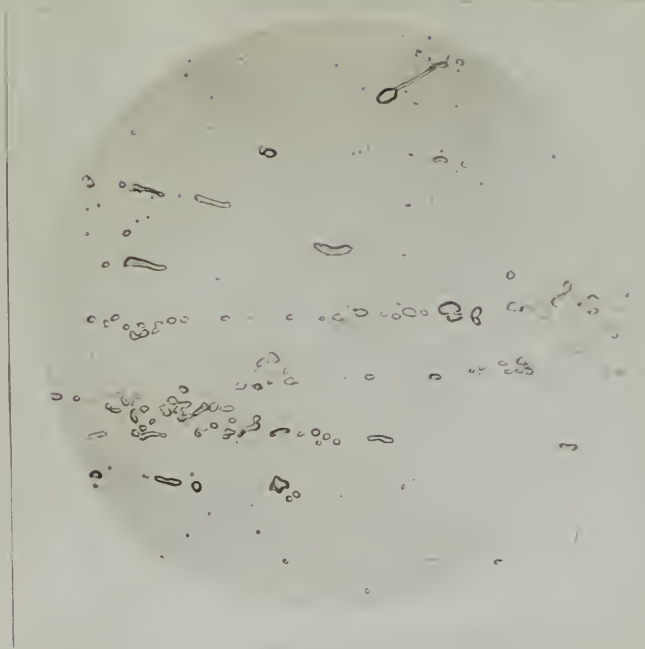
LIQUIDUS AND SOLIDUS DETERMINATIONS



Alloy #1

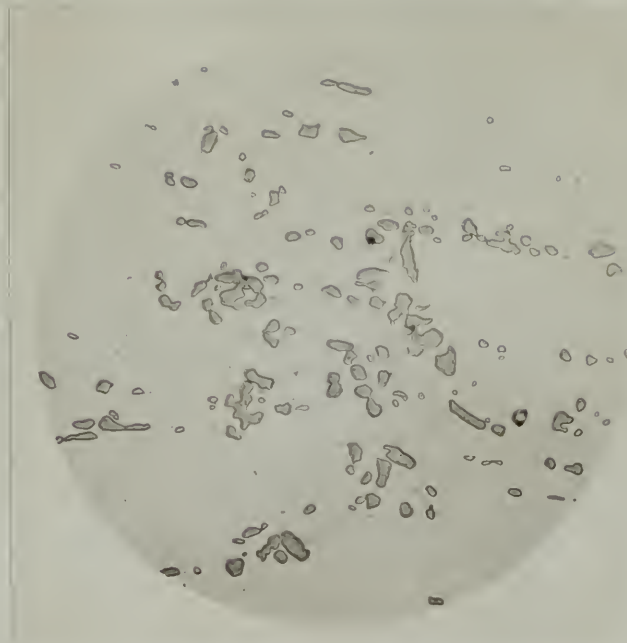
Quenched from 590°C.
Unetched X500





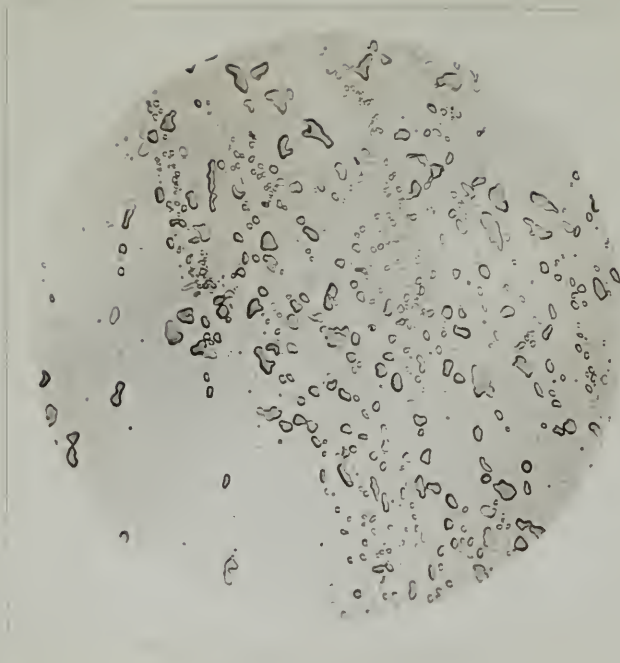
Alloy #2

Quenched from 590°C.
Unetched X500



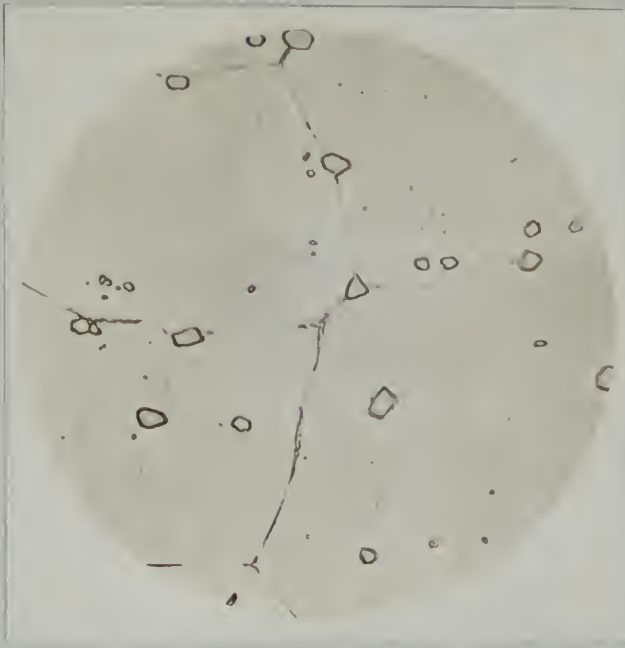
Alloy #3

Quenched from 590°C.
Unetched X500



Alloy #4

Quenched from 590°C.
Unetched X500



Alloy #2

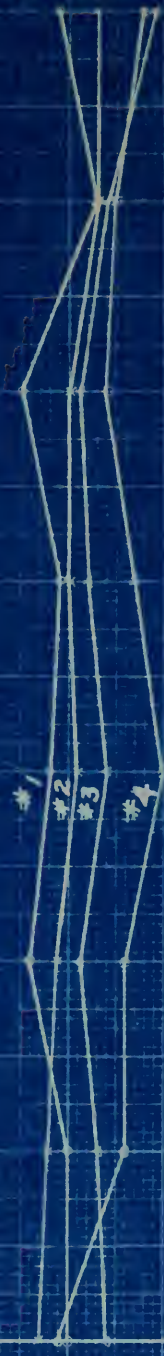
Quenched from 618°C.
1% HF etch X500

PLATE 8

600 550 500 450 400 350 300 250
Degrees Centigrade

Rockwell B (100=0)

120
110
100
90
80
70



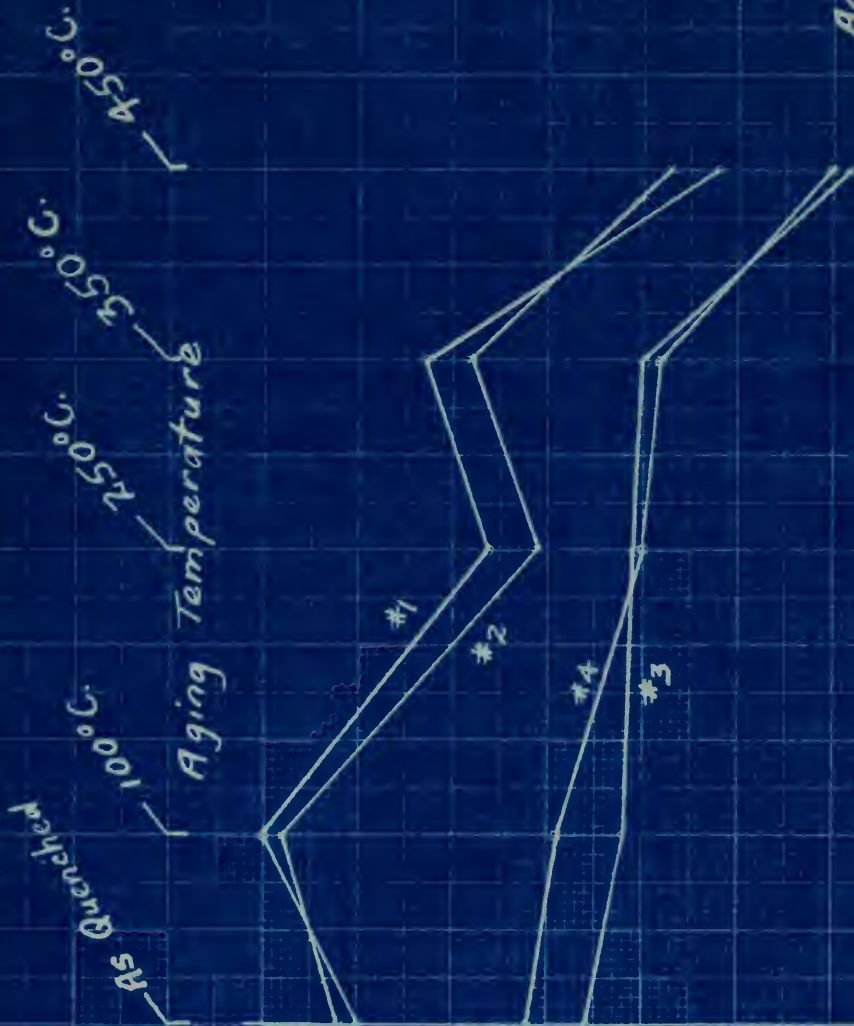
HARDNESS
VS.

QUENCHING TEMPERATURE

Alloys Hot-rolled.

Rock

PLATE 9



Rockwell F (1/8" ball, 100 kg. load, B scale)

HARDNESS
VS.
AGING TEMPERATURE
Alloys Hot-rolled.
8/26/40

PLATE 10

PHYSICAL PROPERTIES
 VS.
 HEAT TREATMENT
 Alloy #1 18%Ni

— Cold Rolled
 — Quenched
 — Aged 100°C
 — Aged 250°C
 — Aged 350°C
 — Aged 450°C

Percent Elong. and RA = Rockwell E Hardness
 lb/in.² - T.S. and Y.P.

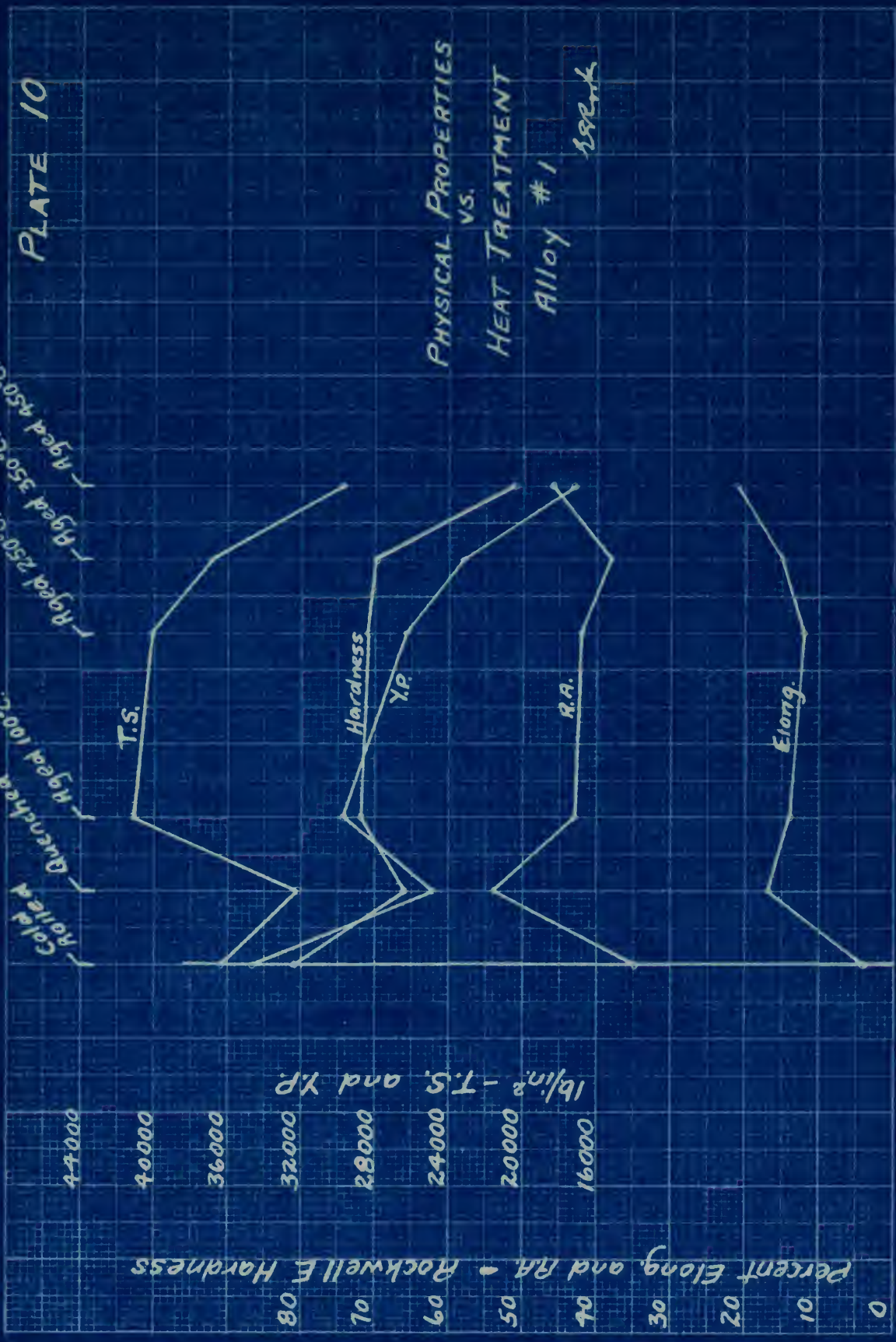


PLATE II

PHYSICAL PROPERTIES
VS.
HEAT TREATMENT
Alloy # 4
Steel

Cold Rolled
 — Quenched
 — Aged 100°C.
 — Aged 250°C.
 — Aged 350°C.
 — Aged 450°C.

Percent Elong. and R.A. — Rockwell F. Hardness
 T.S. and Y.P. lb/in^2

36000
 32000
 28000
 24000
 20000
 16000
 12000
 8000
 4000
 0

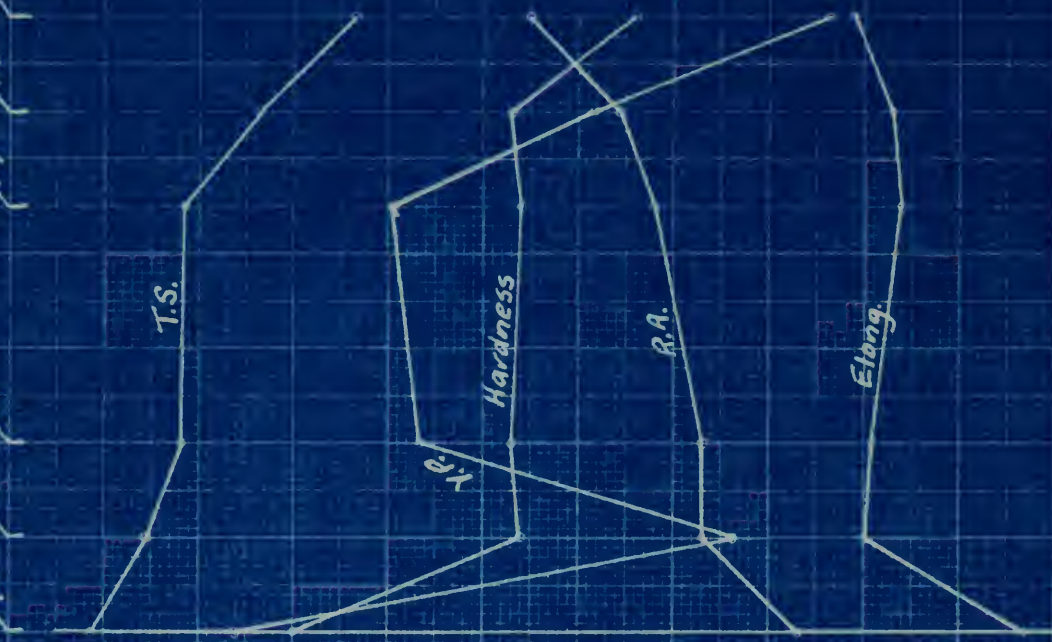


PLATE 12

TENSILE STRENGTH, ELONGATION vs.

HEAT TREATMENT

Alloys #1 and #4
55 Rock

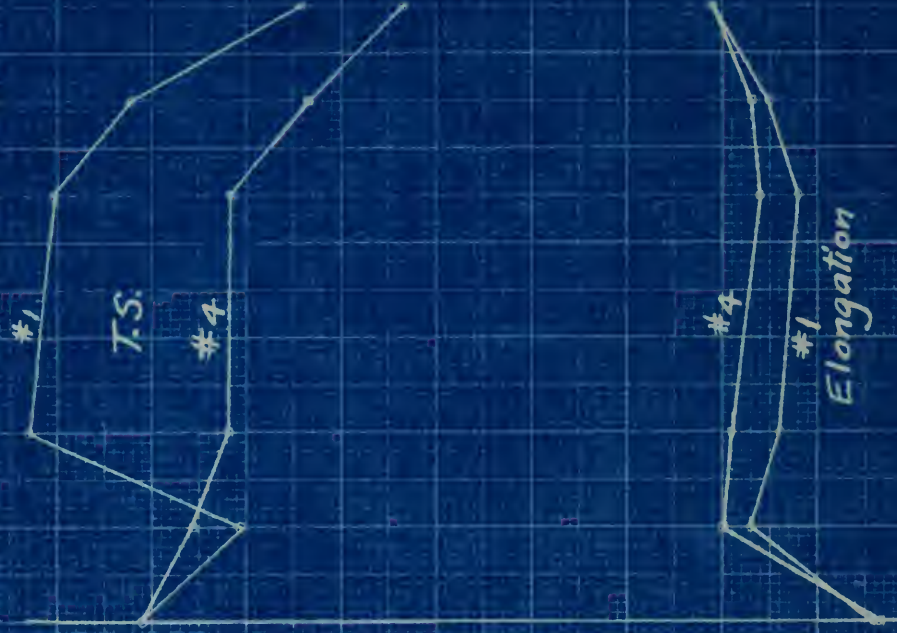
Cold Rolled
 Quenched
 Aged 100°C
 Aged 250°C
 Aged 350°C
 Aged 450°C

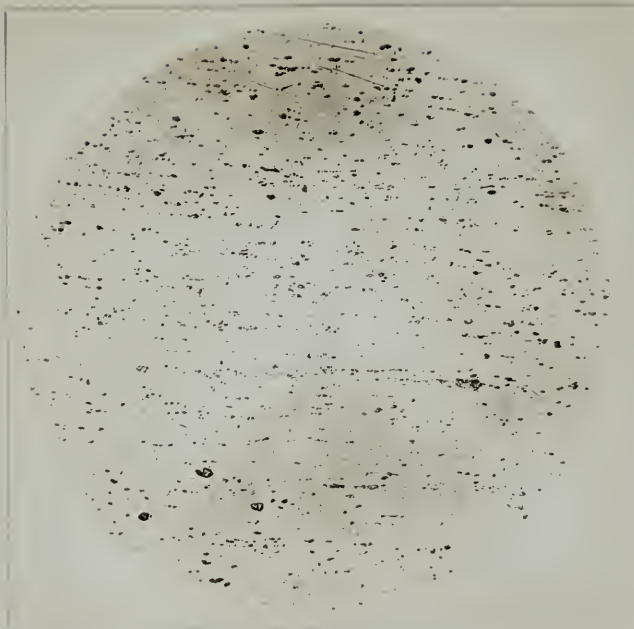
44000
 40000
 36000
 32000
 28000
 24000

lb/in² Tensile Strength

30
 20
 10
 0

Percent Elongation





Alloy #1

Quenched from 590°C.

Aged at 100°C.

1% HF etch X100



Alloy #4

Quenched from 590°C.
Aged at 100°C.
1% HF etch X100

IV. Discussion of Results and Conclusions

11. The hardness tests of the alloys in the condition as quenched from various temperatures (see Plate 8) show nothing that can be called conclusive evidence of precipitation. It will be noted that while the hardnesses of the lower nickel alloys are consistently higher than those for the higher nickel alloys the values are practically constant over the range of quenching temperatures. The 1/16" ball (Rockwell B) is too small for this soft material but was considered satisfactory inasmuch as the results are purely relative and all hardnesses were nearly equal. The values obtained are all less than zero (Rockwell B) but assurance was obtained during the testing that the load was applied only through the ball.

In the composition range examined, the liquidus temperature decreases from 648°C. for the low-nickel alloy to 635°C. for the higher-nickel alloy (Plate 2). The solidus temperature is practically the same for the four alloys. While the rates of heating and cooling used were slightly high (4°C. per minute) the agreement between the heating and cooling temperatures indicates that any lag developed was not of serious consequence. The solidus temperature is the more important of the two because of the fact that with a rising temperature any intergranular melting will begin at that point. In the blast within the gun this would allow grains to be blown loose from the main mass of metal. If this intergranular melting is not begun it is believed that the metal, even though reduced in strength due to the elevated temperature, will have

1. The specimens tested at 500°C in the com-

pression machine from various temperatures (see Table I)

showed that they can be called compressive strength of
specimens. It will be noted that while the specimens

of the lower nickel alloys are nominally higher than

those for the higher nickel alloys the values are prac-

tically constant over the range of quenching temperatures.

The yield strength (Table II) is too small for the yield

strength but was considered satisfactory because as the

specimens are purely relative and all specimens were equally

equal. The values obtained are all less than those (Table III)

of the specimens was obtained during the testing time and

load was applied only through the ball.

2. In the compression range examined, the specimens

temperature decrease from 450°C. for the low-nickel alloy

to 650°C. for the high-nickel alloy (Table II). The

specimens temperature is practically the same for the low

alloys. While the rates of heating and cooling used were

slightly high (50°C. per minute) the agreement between the

heating and cooling temperatures (see Table III) may be

considered as one of certain experiments. The higher

temperature is the more important of the two because at

the test time a higher temperature was maintained

cooling will begin at that point. In the high alloy the

low alloy would also prefer to be slow from the main

mass of metal. It is interesting to note that in the

it is believed that the metal, over short periods in

strength due to the elevated temperature will have

sufficient strength to withstand the blast. Solidus temperature will also depend on amounts of impurities present. It was for this reason that the so-called high purity grade 7A was chosen as the basic metal rather than the ordinary "commercially pure aluminum." In the 51S alloy there is an excess of silicon which invites reference to the statement of Archer in Edwards, Frary, and Jeffries book⁶ that the solidus in Aluminum-Magnesium-Silicon alloys having Si in excess of the Mg_2Si ratio occurs at approximately $550^{\circ}C.$ with the freezing of the ternary eutectic. The final solidification probably takes place at a still lower temperature in 51S due to the presence of impurities. A comparison of the solidus temperatures of the subject alloys with those of the alloys 2S and 51S shows

Alloy	2S	Al-Cu-Ni	51S
Solidus temperature	$658^{\circ}C.$	$620^{\circ}C.$	$550^{\circ}C.$

Thus, solidus temperature and with it resistance to intergranular melting for the Aluminum-Copper-Nickel alloys is seen to compare favorable with the 2S as against the 51S alloy.

The study of the microstructure revealed that the four alloys fall into two groups; the first group being the two low-nickel alloys and the second group being the two higher-nickel alloys. It was noted that over the whole range of temperatures from which quenched the alloys consisted of a ground mass of solid solution with scattered inclusions lo-

sufficient strength to withstand the blast. Solids less
 porous will also depend on amount of impurities present.
 It was for this reason that the so-called high purity grade
 VA was chosen as the basis metal rather than the ordinary
 "commercially pure aluminum." In the alloy there is
 an excess of silicon which implies relationship to the metal-
 lurgical studies of Edwards, Perry, and Lathrop that
 the silicon in aluminum-silicon alloys having 10
 in excess of the $Mg_{2}Si$ ratio occurs at approximately 350°C.
 with the freezing of the primary eutectic. The final
 solidification probably takes place at a still lower tem-
 perature in this due to the presence of impurities. A com-
 parison of the solidus temperatures of the subject alloys
 with those of the alloys 22 and 23 shows

Alloy	22	Al-0.0-11	23
Solidus temperature	600°C.	620°C.	630°C.

These solidus temperatures and with 11 resistance to inter-
 granular welding for the Aluminum-Copper-Nickel alloy is
 seen to compare favorably with the 22 as against the 11
 alloy.

The study of the microstructure revealed that for low
 alloys fall into two groups: the first group being the low
 low-nickel alloys and the second group being the low nickel-
 nickel alloys. It was noted that over the whole range of
 temperatures from which quenched the alloys consisted of a
 great mass of solid solution with scattered inclusions in-

cated largely at the grain boundaries. These inclusions were seen to increase with added nickel but at a faster rate, i.e., there are more than eight times as many inclusions in the 4% nickel alloy as in the alloy containing $\frac{1}{2}$ % nickel. In the first group the inclusions were wholly the ternary compound, T^5 or Cu-Ni, as identified by the methods of Dix and Keith⁸. In the second group there appears a greatly increased amount of the ternary compound together with a large amount of $NiAl_3$. The presence of any $CuAl_2$ in any of the alloys at the as-quenched temperatures was not noted. While the short time of soaking is not sufficient to allow complete equilibrium to be reached the results obtained are believed to be qualitatively accurate. It is believed that this distribution effect is due to the normally strong attraction of nickel for copper. With small amounts of nickel present some of the copper combines with it and aluminum to form the ternary compound while the remainder goes into solution. With higher nickel content less of the copper goes to form solid solution and more forms the ternary compound until a point is reached where a large excess of nickel is needed to draw copper from solid solution in the aluminum. Nickel over and beyond this critical concentration would then unite with the aluminum and appear as $NiAl_3$. This is found to be the case for, with nickel over 1%, free $NiAl_3$ is present. Both the ternary compound and the $NiAl_3$ appear as fairly large rounded particles, mostly at grain boundaries, and would be expected to have a negative effect on physical properties. This is corroborated by the physical data for the higher-nickel alloys.

... of the grain boundaries. These inclusions were
... with added nickel was a larger volume.
... many inclusions in the
... nickel alloy as in the air containing $\frac{1}{2}$ nickel. In the
... the inclusions were chiefly the ferrous compound,
... as identified by the method of Hill and Keith.
... there appears a greatly increased amount
... of the ferrous compound together with a large amount of Ni_3Fe .
... in any of the alloys at the annealing
... This the exact time of annealing
... to be reached
... the results obtained are believed to be qualitatively ac-
... It is believed that this distribution effect is due
... of nickel for copper.
... of the copper
... to form the ferrous compound
... with higher nickel
... to form solid solution and
... nickel is needed
... to draw copper from
... nickel over and beyond
... than with the
... This is found to be the case
... with the
... as fairly large
... and would be
... on physical properties.
... by the physical data for the differ-
... nickel alloys.

Nickel, therefore, having the power to take up and combine with all available copper to form the ternary compound as a rounded inclusion will act as a scavenger for the grain boundaries. While with proper treatment there is small likelihood of there being present any copper-aluminum eutectic, it is not an impossibility and the function of the nickel would be to draw this eutectic up into an inclusion much in the same manner that manganese is said to combine with sulphur in steel and form a rounded particle. This would remove the eutectic which might be present at grain boundaries and which, with its comparatively low melting point, 548°C. , would allow early melting and disintegration.

It was originally intended to determine precisely the physical properties for the complete set of alloys with varying heat treatments. This phase of the work has had to be shortened, however, due to a lack of time. The heat-treating of the tensile specimens was done in an electric resistance furnace with the specimens buried in sand in a sheet metal container and the temperature manually controlled to offset a large temperature gradient within the furnace and a poor automatic control. It was due to lack of a close automatic control that only comparatively short time of aging was used. All tensile properties were determined across the direction of rolling. The testing machine was a Tinius Olsen 50000-pound machine using a light poise to convert it to a 5000-pound maximum load. It was run at minimum speed. Yield points were determined by the drop of the beam and noting change in rate of application of load.

To be noted on physical properties is the fact that

1940. Therefore, having the means to take up and

combine with the available copper to form the necessary com-
pounds as a bonded inclusion will not be a necessary factor for the

grain boundaries. While the proper treatment there is

small likelihood of there being present any copper-nickel

inclusion it is not an impossibility and the focus on at the

inclusion would be to draw the attention of the metallographer

such as the same manner that manganese is said to combine

with sulfur in steel and form a bonded particle. This

would remove the inclusion which might be present at grain

boundaries and which, with its nonagglomerative few rolling

planes, would give rise to a rolling and distortion.

It was originally intended to determine precisely

the physical properties for the complete set of alloys with

varying heat treatment. This phase of the work has had to

be abandoned, however, due to a lack of time. The heat-

treatment of the metal specimens was done in an electric

resistance furnace with the specimens heated in sand in a

steel metal container and the temperature manually con-

trolled to within a large temperature gradient with the

turning and a poor automatic control. It was due to lack

of a more automatic control that only comparatively short

time of aging was used. All tensile properties were de-

termined across the direction of rolling. The tensile machine

was a Tinius Olsen 5000-pound machine using a light roller

to support it in a fixed-angle working tank. It was due to

machine speed. Yield points were determined by the use of

the beam and using strain in case of application of load.

To be noted as physical properties in the fact that

the material hot-rolled easily and on cold-rolling showed a clean smooth finish with no tearing. The final reduction in the cold state was fifty percent.

Just as the four alloys fall into two microstructure groups so do they fall into two groups in hardness values after heat treatment (Plate 9). The two alloys of higher nickel content are slightly softer than the two low-nickel alloys and do not respond an equal amount to heat treatment. This would be expected considering the larger number of inclusions present and consequently a smaller amount of dissolved copper with the higher nickel content, just as we would not expect a one-tenth carbon steel to be as heat-treatable as one with higher carbon. It was assumed that other physical properties would likewise show a division and only the high and low nickel alloys were tested for physical properties. Plates 10 and 11 show the physical properties of the two alloys while Plate 12 shows a comparison of their tensile strength and elongations.

The solution heat treatment, i.e., quenching from near the solidus, followed by aging at 100°C., is considered to give the best combination of properties to these alloys.

Ni. content	T. S. #/in ²	Y. P. #/in ²	Elong. 2" %	R. A. %	Hardness Rockwell E
½%	41200	29700	14	43	72
4%	32700	22700	19	37	57

It will be noted that the lower-nickel alloy is the stronger and harder of the two.

The material for this study was an air-dried sample of
 about 1000 g of material. The final reduction in
 the air state was 100%.

That on the low side the air is not
 enough to be fully dried the air is not
 after each treatment (Table 1). The air is of higher
 initial content and slightly higher than the air
 after and is not reduced to a low amount in heat treatment.
 This would be expected considering the higher number of in-
 creased in weight and content of water in air.
 The air is of higher content than the air after
 would not expect a constant weight of air to be
 possible in air with higher content. It was assumed that
 when physical properties would increase with a division
 and only the high and low weight air was tested for
 physical properties. Tables 10 and 11 show the physical
 properties of the low air state while Table 12 shows a com-
 parison of their relative weights and densities.

The weight of the material is 1.00 g according to
 from the relative weight of 1.00 g. It is considered
 to give the best comparison of properties in low air.

Weight	Volume	Density	Relative weight	Relative volume
1.00	1.00	1.00	1.00	1.00
0.95	0.95	1.05	0.95	0.95
0.90	0.90	1.11	0.90	0.90

It will be noted that the lower-weight air is the lighter
 and denser of the two.

12. The results comparable with those of Read and Greaves in their work on the physical properties of this system⁴ show good agreement. For the 92:4:4 Al-Cu-Ni. (nominal composition) alloys:

		Present Work	Read and Greaves
Cold # Worked	{ Yield Point	30500	29600
	{ Tensile Strength	36500	36800
	{ Elongation	3.3	3.8
	{ Reduction Area	27	6.2
Annealed at 450°C.	{ Yield Point	5400	7200
	{ Tensile Strength	25400	25300
	{ Elongation	21	23.5
	{ Reduction Area	55	29.7

#Present work on sheet reduced cold about 50% in cross section to .064". Read and Greaves on 1" red cold drawn to 7/8".

It will be noted above that the greatest disagreement is confined to those properties, Yield Point and Reduction of Area, in which positive values are difficult to determine.

The alignment of the four alloys into two groups with the division at between one and two percent. nickel which was shown by the microscope and hardness tests agrees in general with the diagram of Bingham and Haughton.⁵ They place a phase boundary at between one and two percent. nickel. The liquidus temperatures also show good agreement. A marked disagreement is shown in the solidus

18. The results compared with those of Reed and Steyer in their work on the physical properties of this system also show agreement. For the 20-80 Al-20-80 (nominal composition) alloy:

Alloy	Yield Point	Tensile Strength	Elongation	Reduction Area
20-80	20000	30000	2.5	0.8
20-80	20000	30000	2.5	0.8
20-80	20000	30000	2.5	0.8
20-80	20000	30000	2.5	0.8

It will be noted above that the present discussion is confined to those properties, Yield Point and Reduction Area, in which positive values are difficult to determine. The alignment of the test alloy with the cross-section of the specimen at the point of fracture is shown by the microscope and hardness tests given in general with the diagram of Figure 1. The phase boundary of between the two phases is shown. The liquidus temperature also shows some agreement. A correct alignment is shown in the solid

temperatures, however. In their determinations a great amount of difficulty was encountered in interpreting a number of minor halts in the cooling curves (inverse-rate). A close determination of solidus temperature under these circumstances is impossible but it is believed probable, as they state, that these minor halts were due to metastability in the liquid. On heating many of these retardations were not in evidence. In the present work solidus points were determined on time-temperature rather than inverse-rate curves. The inverse-rate curve, while it does give more definite determinations, also magnifies any experimental errors to a point where they may complicate the interpretations. The uniform results obtained in the present work lend assurance to the correctness of the determinations and the later work on heat treating, i. e., the solution heat-treatment consisting of soaking at $590^{\circ}\text{C}.$, shows positively that the solidus is above $585^{\circ}\text{C}.$, the temperature determined by Bingham and Haughton. These variations may, of course, be due to different amounts of impurities. No explanation is attempted for the still greater disagreement in solidus temperatures for the low-nickel alloy.

13. It is reiterated here that the only test which will give positive indication of the adaptability of this group of alloys to use in cartridge cases must be actual application. We can, however, make an estimate of this adaptability by examining the above data in the light of past experiment. The alloys designedly have a low specific gravity. The only advantage an alloy of higher nickel content might have over the low nickel alloy might be the presence of NiAl_3 .

temperature, however. In their determination a small amount of dilution was encountered in interpreting the number of atoms held in the cooling curves (inter-plate). A close determination of solidus temperatures under these circumstances is impossible but it is believed probable, as they state, that these inter-plate curves are in substantial agreement with many of those reported in the literature. In the present work certain points were determined on the temperature-plate curves from inter-plate curves. The inter-plate curves, while it does not have definite determinations, also mentioned any experimental errors to a point where they may complicate the inter-plate curves. The curves remain unchanged in the present work and agreement in the curves of the determinations and the inter-plate curves, i.e., the solidus curve. Treatment consisting of cooling at 100°C. shows positively that the alloy is above 500°C. the temperature determined by Blagden and Houston. These variations may, of course, be due to different amounts of impurities. An explanation is attempted for the solidus displacement in alloys prepared for the inter-plate alloy.

It is believed that the only test which will give positive indication of the solubility in this case is alloy to use in centrifuge tubes and be cooled rapidly. It was, however, with an excess of this solubility in examining the above data in the light of past experience. The alloy definitely has a low specific gravity. The only evidence in alloy of higher nickel content is that even the low nickel alloy might be the presence of Ni₃Al.

With what may be called an excess of nickel present, it is extremely unlikely that any copper could exist outside of either the solid solution or the ternary compound. It is believed possible, however, that the smaller amount of nickel, one-half percent., is sufficient to spheroidize whatever free copper might be available as the ternary compound. Consequently, our consideration will devolve upon the low nickel alloy ($95\frac{1}{2}:4\frac{1}{2}$ Al:Cu:Ni). It is composed initially to avoid the presence of any impurities which might allow earlier melting. When annealed at $450^{\circ}\text{C}.$, its hardness, elongation, and reduction of area would indicate that it could be as easily drawn as the alloys 17S (duralumin) and 25S (silicon-manganese alloy), probably slightly more so. In the recommended heat-treated condition (quench at $590^{\circ}\text{C}.$, aged at $100^{\circ}\text{C}.$) it has sufficient strength and hardness for all except rough usage. It has a solidus temperature comparable with that of the commercially pure aluminum, which, while not high, might be sufficiently elevated to prevent disintegration. At elevated temperature however, it is extremely soft and care must be taken when heat-treating not to strain it in any manner. Evidence of this softness occurred in attempting to heat-treat a specimen made up of laminations screwed together. The strain on the screw-head caused it to sink deeply into the outer metal when the metal was heated prior to quenching. Whether or not this softness will cause failure in the cartridge case during the firing is a subject for conjecture. Alloy 51S was not extruded into the extractor recess as much as alloy 2S and at the same time alloy 2S did not suffer from disintegration to

With what may be called an excess of nickel present. It is
extremely unlikely that any copper could exist outside of
either the solid solution or the matrix compound. It is
believed possible, however, that the small amount of
nickel present is sufficient to precipitate
whatever free copper might be available in the matrix com-
pound. Consequently, our composition will deviate from
the low nickel alloy (99.99% Ni-0.01% Cu). It is composed
entirely to avoid the presence of any impurities which
might allow earlier melting. Iron annealed at 650°C.
the presence, elongation, and reduction of area would
indicate that it could be as small as the alloy
1% Ni (Germanium) and 99% (Silicon-manganese alloy). Probably
slightly less so. In the recommended heat-treated condition
[anneal at 600°C., aged at 150°C.] it has sufficient strength
and hardness for all useful tests made. It has a surface
roughness comparable with that of the commercial alloy
aluminum, which, while not high, might be sufficient
to cause a severe strain hardening. At elevated temperature
however, it is extremely soft and may want to be used when
heat-treated and in strain is in any manner. Evidence of
this nature occurred in specimens of heat-treated specimen
made up of individual layers together. The strain on the
cross-head caused it to slip locally into the over head when
the metal was heated prior to quenching. Working in hot zinc
solution will cause failure in the specimens even during the
lifting in a liquid for comparison. Alloy 99.99% Ni-0.01% Cu
traced into the structure reveals as much as alloy 99.99% Ni-0.01% Cu
the same time alloy 99.99% Ni-0.01% Cu from disintegration to

to the same extent that the 51S did. It might be expected that the Al-Cu-Ni alloy would resist disintegration equally as well as the 2S and that it would resist extrusion as well as the 51S.

The general conclusion is that a trial of this alloy in actual use would be worthwhile. It is not a conviction that it will be more adaptable than the standard commercial alloys but there is in its favor as against them, the difference in impurities and absence of alloying additions which might allow earlier melting.

14. A continuation of this work along the following lines would be advisable: (1) Testing of the chosen alloy by actual application (Commercial application of an alloy based on grade 7A aluminum would not be practical. But while it is desirable to have impurities a minimum, it is believed possible that use of a commercially practical high-purity grade of aluminum would give satisfactory results); (2) Determination of the physical properties of the two intermediate alloys of this group, noting any critical nickel content which would be expected at between one and two percent.; (3) Further determination of solidus temperatures working with alloys having varying amounts of impurities purposely added; (4) Further determinations of effects of heat-treatment involving a variation in time of aging, and quenching from temperatures below that used in the present work.

to the same extent that the 518 bill. It might be expected
that the Al-Ge-Ni alloy would resist oxidation equally
as well as the 52 and that it would resist oxidation as well
as the 518.

The general conclusion is that a trial of this alloy in
actual use would be worthwhile. It is not a conviction that
it will be more adaptable than the standard commercial alloys
but there is in its favor an argument that the difference in
properties and absence of alloying additions which might
allow earlier melting.

14. A continuation of this work along the following
lines would be advisable: (1) Testing of the chosen alloy
by actual application (Commercial application of an alloy
based on these 72 elements would not be practical. But while
it is desirable to have described a minimum, it is desirable
possible that use of a commercially practical composition
of aluminum would give satisfactory results.) (2) De-
termination of the physical properties of the two intermetallic
alloys of this group, making any critical metal content which
would be expected to be between one and the second. (3) Further
determination of similar temperatures working with alloys having
varying amounts of interstitially dissolved (a) further
determinations of effects of heat-treatment involving a
variation in size of grain, and quenching from temperatures
below that used in the present work.

V Appendix.

15. Relative References and Notes.

- 1 Note: Fixed ammunition is the term applied to the charge for a gun where the propellant is contained in a cartridge case which is fixed to the projectile, the two constituting a unit mass; e.g., all pistol ammunition is fixed ammunition.
- 2 "Report on Conditions Developed in the Firing of Aluminum Cartridge Cases", Naval Gun Factory Report, 18 April, 1929, C.E. Margerum.
- 3 "Light Metals and Alloys, Aluminum, Magnesium", Circular of the Bureau of Standards, No. 346.
- 4 "The Properties of Some Aluminum-Nickel and Copper-Nickel-Aluminum Alloys", Read and Greaves, J.Inst.Met., 13, 100-159
- 5 "The Constitution of Some Alloys of Aluminum with Copper and Nickel", Bingham and Haughton, J.Inst.Met., 29, 71
- 6 "The Aluminum Industry", Edwards, Frary, and Jeffries, Vol. 2, Aluminum Products and Their Fabrication.
- 7 "Metallurgy of Aluminum and Aluminum Alloys", R.J. Anderson.
- 8 "The Etching Characteristics of Constituents in Commercial Aluminum Alloys", Dix and Keith, Proc.A.S.T.M. 26
- 9 2S Aluminum Co. of America commercially pure (99%+) aluminum, principal impurities iron, silicon, and copper.
- 10 51S Aluminum Co. of America alloy. Nominal composition: 1% silicon, 0.6% magnesium, remainder aluminum plus impurities.
- 11 7A Aluminum Co. of America highest purity (99.95%) aluminum.

13. Relative Potentials and Values.

1. The first condition is that the alloy should be a solid solution of the components in the liquid state. The second condition is that the alloy should be a solid solution of the components in the solid state. The third condition is that the alloy should be a solid solution of the components in the solid state.

2. Report on conditions developed in the firing of Aluminum Oxide Cells, Naval Air Development Report, 18 April, 1922, O. N. Hagerman.

3. Light Metals and Alloys, Aluminum, Magnesium, Titanium of the Bureau of Standards, No. 248.

4. The properties of some Aluminum-Nickel and Copper-Nickel-Aluminum Alloys, Res and Resv, J. Ind. Met., 15, 100-105.

5. The Constitution of Some Alloys of Aluminum with Copper and Nickel, Richards and Hurdson, J. Ind. Met., 15, 71.

6. The Aluminum Industry, Kowalski, Perry, and Lott, Vol. 2, Aluminum Industry and their Application.

7. Metallurgy of Aluminum and Aluminum Alloys, T. T. Anderson.

8. The Working Characteristics of Aluminum in Compression, Aluminum Alloys, Six and Seven, Iron, A. S. T. 15.

9. Aluminum Co. of America, Aluminum Alloys, Six and Seven, Iron, A. S. T. 15.

10. Aluminum Co. of America, Aluminum Alloys, Six and Seven, Iron, A. S. T. 15.

11. Aluminum Co. of America, Aluminum Alloys, Six and Seven, Iron, A. S. T. 15.

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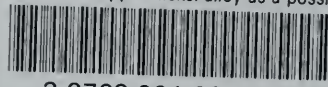
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